Phase 1 - Experimental Study of Ultra Cold Neutron Localization and Sub-barrier Penetration

DOE Project DE-FG07-98ID13646

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Report Period: July 1, 1998 – June 30, 1999

The goal of this project is to examine a possible cause of the anomalous loss rate of ultra cold neutrons (UCN) in UCN storage bottles. Serebrov (PNPI, Russia) theorized that the anomalous loss rate was due to enhanced UCN absorption and upscattering on impurity atoms as well as enhanced sub-barrier penetration, where the enhancements are the result of localization of UCN at defects such as vacancies, voids, grain boundaries, etc.

We will test Serebrov's ideas by making parametric measurements on Be and stainless steel (SS) samples implanted with various ions in order to have known and large concentrations of defects and impurity atoms. The rotor converter UCN source at Los Alamos National Laboratory and the reactor-based variable-energy slow positron beam at The University of Texas at Austin will be used for these experiments. The measurements and their interpretation are the subject of a PhD dissertation by a graduate student who is being supported by this NEER grant. Our project will also contribute to the advancement of using UCN for materials research, a field that is in its infancy.

Objective 1: Study UCN and Positron Physics (6 Months)

<u>UCN Physics</u>

We have accumulated and studied over 150 references on ultra cold neutrons. From these references we have obtained a better understanding of the more advanced theoretical aspects of the subject and a comprehensive picture of previous UCN measurements. The principal investigator visited the UCN group at the LANSCE facility at Los Alamos National Laboratory where he obtained insight into the latest UCN physics.

Some of the more relevant information from our studies are given below.

A recent analysis of beryllium UCN bottles by Alfimenkov, et al. shows the contamination and temperature dependence of UCN loss cross section in detail. At very low temperatures (less than 20 K), the loss cross section was found to be 0.9 barns, which is about two orders of magnitude higher than what is theoretically expected. The experiments by Golikov, et al. where beryllium powder was used, gave consistent results. The reviews by Golub (Berlin) give detailed information about some of the earlier experiments on UCN storage. Explanations that were put forward to explain this "anomaly" of high UCN loss rates are the following: (*i*) a correction to the optical theory that included the possibility of channeling, (*ii) q*uasi-elastic scattering with very small energy transfer to UCN (in the order of 10^{-6} eV), (*iii)* high frequency vibrations or phonons in the solid which could interact with the UCN providing enough energy to the UCN to escape from the bottle. These hypotheses on heating are discussed by Blokhintsev and Plakida. Early results, such as those given by Strelkov and Hetzelt (1978) show heating up to 20 meV. However recent experiments by Bestle, et al. and Steyerl, et al. (1997) give only a very small heating of about 5 x 10^{-11} eV. (*iv)* losses due to surface roughness, impurities and surface contamination.

None of the theoretical and experimental analyses of these factors have given high enough loss rates to explain the anomaly. This has resulted in consideration of even more exotic effects. Steyerl and Malik discuss the possibility of presence of an accompanying wave function and energy levels that come up as a result of application of the uncertainty principle to the dynamic properties of the UCN. They claim that the new energy levels may further cool the UCN while it moves to excited states thus losing energy. The cooled neutrons may not be lost, but cannot reach the detector due to their low energies.

The time that the neutron spends during tunneling through a solid (dwell time) and absorption probability during that time has been calculated by Golub, et al. (1990) using a first principles approach. A more detailed analysis of dwell times is given by Hauge and Stovneng. Serebrov has given a theoretical description of the localization process and with Romanenko, calculated the effects of localization to the absorption properties of the solid. Abele et al. have searched for the localization of UCN in disordered materials theoretically using Anderson localization and experimentally. Dubbers has given some introductory information about their results, which show that the neutrons tend to localize in potential wells present in such media.

Positron Physics

We have all the relevant publications and references on positron physics which is better understood than UCN physics. Through a collaboration established with the Brookhaven National Laboratory, our graduate student was sent to the positron beam facility there to gain hands-on experience on positron beam experiments while studying positron physics with experts in the field.

When a beam of positrons is incident on a solid, they quickly slow down to kT energies. The implantation profiles of the positron in a solid vary with respect to initial energy, allowing researchers to perform depth profiling by changing the implantation energy. After slowing down, positrons diffuse as a delocalized Bloch wave in a perfect solid. In the case of imperfections, positrons, repelled by the positive potential of the nuclei, will tend to be trapped in vacancies in the solid. The positron thermalization can be described by the Fokker-Planck equation. The analysis of trapping phenomena in arbitrary geometries is based on multigroup diffusion-annihilation equations.

Objective 2: Design UT and LANL experiments (6 Months)

UT Experiments

To become familiar with the implantation process, Be and SS test samples were purchased. These test samples were polished and analyzed with scanning electron microscopu to characterize their pre-implantation surfaces. We are planning transmission electron microscope measurements to get information about grain boundaries. Some of the Be and SS test samples were sent to Texas A&M University for ^{3}He implantation. The spot size of the ^{3}He beam is about 0.8 cm. The ^{3}He implantation profiles have been calculated with the TRIM code and measured by neutron depth profiling using the permanent neutron depth profiling facility at the UT-Austin research reactor. From these preliminary studies, we have characterized the ion concentration and damage distributions of ^{3}He implanted in Be and SS samples. Implant doses that are required for UCN measurements at LANL are determined from these characterizations.

The development of the Texas reactor-based variable-energy slow positron beam facility has not progresses as rapidly as planned. The PI and graduate student have spent considerable time on the installation of this facility at a beam port of the UT-Austin research reactor. The positron moderator and optics were designed and constructed at UT-Arlington; these components did not arrive at UT-Austin until February 1999.

For the proposed defect measurements, a positron beam with a preset energy is focued onto the sample. A HPGe detector is used to detect the g 's which are emitted as a result of annihilations of positrons with electrons in the sample. The HPGe detector has been obtained and the sample chamber has been designed.

LANL Experiments

Arrangements have been made to use the rotor converter UCN source for the proposed measurements. The target date for these measurements is in October 1999 and involves moving a UCN storage bottle from the prototype solid deuterium UCN source to the rotor converter UCN source and modifying this bottle to filter out high energy UCN to set the maximum UCN energy. The design of systems for the detection of UCN capture by implanted ions and detection of sub-barrier transmitted UCN was discussed. Unlike our progress on the Texas positron beam facility, the UCN group at LANSCE is making remarkable progress on the development and future implementation of a solid deuterium UCN source for a users facility at LANL.